MULTI-OBJECTIVE OPTIMIZATION IN ELECTRO DISCHARGE MACHINING OF Al/B_4C METAL MATRIX COMPOSITES

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PURUSHOTTAM MISHRA

213ME2411

Under Supervision of

Prof. SAURAV DATTA

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
ODISHA-769008, INDIA

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA 769008, INDIA

Certificate

This is to certify that the thesis entitled ***"Multi-objective optimization in Electro Discharge Machining of Al/B_4C Metal Matrix Composites"*** submitted by ***Mr. Purushottam Mishra*** has been carried out under my supervision in partial fulfilment of the requirements for the Degree of ***Master of Technology*** in ***Production Engineering*** during the academic year 2014-15 in the ***Department Of Mechanical Engineering, National Institute of Technology***, ***Rourkela***, and this work has not been submitted elsewhere before for any other academic degree/diploma.

Date:

Rourkela-769008

Dr. Saurav Datta
Assistant Professor
Department of Mechanical Engineering
National Institute of Technology, Rourkela

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Abstract

Al, B_4C metal matrix composites (MMCs) have significant applications in automobiles and nuclear power plants due to its excellent properties compared to other traditional materials. But the machning of MMCs is a big concern and still an area of research. Conventional machining of MMCs causes different problems like high tool wear, poor surface roughness, high machining cost etc.. Therefore, several researchers have used advanced machining methods like EDM, ECM, EBM, AJM etc. for effective machining of composites. EDM can be one of the best Nonconventional machining processes to machine such composites. So in this study EDM have been selected for machining of Al, B_4Cp MMCs to get better quality of product and satisfactory machining characteristics. It is also very important to control and optimize the different process parameters of EDM.. Taguchi method can be used for optimization of different process parameters of EDM but Taguchi method is generally used for optimization of single response. EDM process is involved with multiple responses so a multi-objective (hybrid) optimization technique is need to use for optimization purpose. Therefore, in this study we have worked on selection of optimal parameter (machining) setting of EDM on Al/20%B_4C composites using a hybrid optimization technique that is TOPSIS combined with Taguchi method. Performance parameters like material removal rate (MRR), tool Wear Rate (TWR) and surface roughness (SR) are used to optimize the machining parameters like current (Ip), voltage (V), pulse on time (Ton) etc using TOPSIS combined with Taguchi method.

Keywords— MMCs, electrochemical machining, electro discharge machining, abrasive jet machining, tool wear, TOPSIS etc.

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Chapter 1: Introduction

Metal matrix composites (MMCs) were firstly used by Toyota in early 1980s. After that it finds a vast application in different fields like automobile, aerospace and nuclear power plant engineering. This chapter comprises of brief introduction about MMCs.

1.1 Composite

Composite material consists of two or more constituent materials altering in composition which have different physical or chemical properties. The constituent materials do not dissolve or merge completely into one another means they have their own identities although they act in concert.

The constituent materials that that make up composites are mainly of two types one is matrix binder and other is the reinforcement or filler elements. Matrix binder can be of different types like polymers, metals, ceramics etc. similarly reinforcement can also be of different types like fibers, particles, flakes etc. The Matrix binder provides the bulk form and Holds the reinforcement in an orderly pattern [1].

1.2 Metal Matrix Composites

Composite materials consisting of metallic matrices, reinforced with ceramic particles or fibers, are known as metal matrix composites or MMCs. So MMCs consists of mainly two phases' primary phase that is metal matrix and secondary phase that is reinforcement [1]. The different functions of primary phase and secondary phase are given below:

1.2.1 Functions of the Matrix Material (Primary Phase)

- Provides the bulk form of the part or product made of the composite material.
- Holds the imbedded phase in place, usually enclosing and often concealing it.
- When a load is applied, the matrix shares the load with the secondary phase, in some cases deforming so that the stress is essentially born by the reinforcing agent.

1.2.2 Function of the Reinforcing Phase (Secondary Phase)

- Increase in yield strength and tensile strength of MMCs.
- Improvement of thermal shock resistance.
- Improvement of corrosion resistance.
- Increase in Young's modulus.
- Reduce thermal elongation

According to Imbedded phase shape commonly MMCs are of following types :

- Fibers – SiC, B_4C
- Particles – alumina (Al_2O_3), alumina-silica.

In this study Aluminium is the primary phase (matrix material) and B_4C is secondary phase (reinforcing material) [2-3].

1.3 Advantages, disadvantages and applications of MMCs

The different advantages, disadvantages and applications of MMCs are discussed bellow.

1.3.1 Advantages

Metal matrix composites have a number of advantageous properties as compared to monolithic metals which are following [1]:

- Light Weight
- Performance at higher temperatures
- High Strength
- Low Density
- Better wear resistance
- Lower coefficients of thermal expansion
- High thermal and electrical conductivities
- High fatigue resistance and lower creep rate
- Resistance to most radiations

1.3.2 Disadvantages

- Costly than other conventional materials
- Comlex manufacturing methods
- Costly machining methods (Unconventional machining)

1.3.3 Applications

Metal matrix composites have a high application potential in automotive engineering in braking systems, piston rods, piston pins, pistons, frames, valve spring caps, brake discs, disc brake calliper, brake pads, cardan shaft etc. They have also found application in military and civil aviation in the area of axle tubes, reinforcements, blade and gear box casing, turbine, fan, and compressor blades. In the aerospace industry MMCs have been applied in frames, renforcements, airials, joining elements etc. Some applications are given bellow [4]:

- Partial short fiber reinforced light metal diesel engine piston (Al-SiC MMCs).
- Cast brake disk of particle reinforced aluminium for different vehicles.
- Brake disk in rail engines (Al-SiC MMC).
- Passenger car brake disk and drums of particle reinforced aluminium.
- Drive shaft of particle reinforced aluminium for passenger cars (Al-Al_2O_3 MMC).
- Longitudinal bracing beam (Stringer) of passenger cars of conventional cast iron.
- Fan exit guide vanes in aeroplanes.
- Main cargo bay struts in space shuttles (Al-B_4C MMC).

1.4 Al/ B_4C MMCs and their importance

In this study Aluminium is the primary phase (matrix material) and B_4C is secondary phase (reinforcing material). Al/B_4C MMCs are one kind of Aluminium matrix composites (AMCs). Aluminium matrix composites (AMCs) have many industrial applications which mainly dealing with two kinds of reinforcement: aluminium oxide (Al_2O_3) and silicon carbide (SiC) but Boron carbide (B_4C) can be an alternative to SiC and Al_2O_3 due to its properties.

Boron carbide is the third hardest material after diamond and boron nitride. We can use B_4C as reinforcement in AMCs instead of SiC and Al_2O_3 because boron carbide is as hard as SiC (2800 KH) and harder than Al_2O_3 (2100 KH), and lighter (2.52 g/cm3) than both reinforcements (3.20 and 3.96 g/cm3 respectively) and even aluminium alloy (2.70 g/cm3). There are other attractive properties of Boron carbide like it has good wear resistance and good chemical stability. One of the isotope of Boron B_{10} has good neutron absorbing capacity. Due to the specific ability of the B_{10} isotope to capture neutrons Al–B_4C composites have been used in nuclear industries [5].

1.5 Processing of MMCs

Metal-matrix composites can be processed by several techniques. Some of important techniques are given below [3].

1.5.1 Solid states processing

Solid states processing is an important method for processing of MMCs and generally this method is used to produce MMCs with highest mechanical properties. This method is adopted to obtain homogeneous distribution of reinforcement in the metal matrix so that we get a homogeneous microstructure of composite. Some important solid states processing methods are powder metallurgy, diffusion bonding and Deformation processing:-

- **Powder metallurgy** – In this method the matrix and the reinforcement powders are blended to produce a homogeneous distribution. The blended powder is cold pressed, uniaxially or isostatically and we get green compacted sample. Finally this green compacted sample is sintered in a furnace and we get our product.
- **Diffusion bonding** – This method is mainly used for joining similar or dissimilar metals. The principal advantages of this technique are the ability to process a wide variety of metal matrices and control of fiber orientation and volume fraction.
- **Deformation processing** –This method is used to deform the composite material.

1.5.2 Liquid-State Processing

This method for processing MMCs has many advantages like less costly compare to other processing methods, complex shapes can be produced easily etc. So this method is widely used casting industry. Some important Liquid-State Processing techniques are liquid infiltration, squeeze casting, in-situ process:

- **Liquid infiltration -** This method involves infiltration of reinforcement by a liquid metal. Liquid-phase infiltration of MMCs is not straightforward, mainly because of difficulties with wetting the ceramic reinforcement by the molten metal and reactions between the fiber and the molten metal. So fiber coatings applied prior to infiltration, which improve wetting and allow control of interfacial reactions.
- **Squeeze casting –** This method is also known as pressure infiltration because in this method liquid metal is pressurised or forced into a fibrous or particulate perform.
- **In Situ Processing -**In this method reinforcement phase is formed in situ. One of the best example of in situ processing is Controlled unidirectional solidification of a eutectic alloy. Unidirectional solidification of a eutectic alloy typically results in one phase being distributed in the form of fibers or ribbon in the matrix phase. The relative size and spacing of the reinforcement phase can be controlled by simply controlling the solidification rate.

1.5.3 Deposition techniques

This method is based on diffusion bonding between reinforcement and matrix material. This method involves coating of individual fibers into matrix material to produce the composite structural shape. The main disadvantage of using deposition techniques is that they are time consuming. There are several deposition techniques like immersion plating, electroplating, spray deposition, chemical vapour deposition (CVD), and physical vapour deposition (PVD) etc:

- **Immersion plating** – This method is also known as dipping and is similar to infiltration casting except that fiber tows are continuously passed through baths of molten metal.
- **Electroplating** – Electroplating produces a coating from a solution containing the ion of the desired material in the presence of an electric current. Fibers are wound on a mandrel, which serves as the cathode, and placed into the plating bath with an anode of the desired matrix material.
- **Spray deposition -** This technique typically consists of winding fibers onto a foil-coated drum and spraying molten metal onto them to form a monotape.
- **Chemical vapour deposition -** In the CVD process, a vaporized component decomposes or reacts with another vaporized chemical on the substrate to form a coating on that substrate. The processing is generally carried out at elevated temperatures.
- **Physical vapour deposition –**This method is also used to produce multilayered MMCs, particularly at the nanometre scale.

1.6 Machining of MMCs

In recent year, MMCs find vast applications in different fields because they offer various advantages like high specific strength, high temperature resistance, wear resistance, stiffness etc. So the machining of MMCs is a very important concern. MMCs are consists of a certain amount of reinforcement which is hard and abrasive in nature and causes high amount of tool wear in conventional machining. So carbide cutting tools or poly crystalline diamond (PCD) cutting tools are recommended for conventional machining of MMCs. These cutting tools have high cost so conventional machining of MMCs becomes very costly. Due to high tool wear and high cost of machining nonconventional machining is preferred over conventional machining of MMCs. Nonconventional machining like water jet machining and laser beam machining are used for straight cutting of MMCs and for producing complex shapes on MMCs electrochemical machining (ECM) and electro discharge machining (EDM) are used [29].

1.7 Objective of study

The aim of this study is contributing to enlighten the feasibility of using boron carbide (B_4C) as reinforcement for aluminium matrix composites (AMCs) obtained by solid-state processes (powder metallurgy). For this we performed the experimentation in four stages which are following:

- Al/B_4C MMC preparation by powder metallurgy process.
- Electro discharge Machining of Al/B_4C MMC.
- Analysis of experimental results using TOPSIS combined with Taguchi method.
- Selection of Optimum parameters setting for better machining and quality characteristics.

Chapter 2: Literature review

This chapter gives information about the past work done related to the present study by different literature reviews.

2.1 Al-B_4C MMCs

Composite material consists of two or more materials (the matrix binder and the reinforcement or filler elements), altering in composition. Metal Matrix Composites are composites which consist of metallic matrices. MMCs consist of mainly two phases, primary phase (metal matrix) and secondary phase (reinforcing phase). In this study Aluminium is the primary phase and B_4C is secondary phase. Blank [2] and Saini et al. [3] discussed that Imbedded phase is mainly of two types 1st is Fibers (SiC, B_4C) and 2nd is Particles (Al_2O_3, alumina-silica). Metal matrix composites have a number of advantageous properties as compared to monolithic metals like light weight, performance at higher temperatures, high strength, low density, better wear resistance, lower coefficients of thermal expansion, High thermal and electrical conductivities, Resistance to most radiations etc [1]. According to Ahamed et al. [4] metal matrix composites have a high application potential in automotive and aerospace industry like in making diesel engine piston (Al-SiC MMC), Brake disk of passenger cars (Al-Al_2O_3 MMC) and rail engines (Al-SiC MMC), Fan exit guide vanes of aeroplanes , Main cargo bay struts in space shuttles (Al-B_4C MMC). We can see that AMCs are mostly used in different automotive and aerospace applications which are mainly reinforced with SiC and Al_2O_3. Gomez et al. [5] discussed B_4C can be a good alternative to SiC and Al_2O_3 reinforcing materials in AMCs due to its properties like it is the third hardest material after diamond and boron nitride, Lighter (2.52 g/cm3) than both reinforcements (3.20 and 3.96 g/cm3 respectively) and even aluminium alloy (2.70 g/cm3), Good wear resistance, Good chemical stability, Neutron absorbing capacity (B_{10} isotopes) etc. Due to the specific ability of the B_{10} isotope to capture neutrons Al–B_4C composites have been used in nuclear industries.

2.2 Powder metallurgy Processing

Metal-matrix composites can be processed by several techniques. Saini et al. [3] discussed some of important techniques like Solid State Processing, Liquid state processing, Powder Metallurgy, Direct Processing/Spray Deposition etc. Mostly powder metallurgy processing methods are used to fabricate particulate or fiber reinforced composites. According to Abenojar et al. [6] powder metallurgy typically involves three stages which are Blending, Compacting and Sintering.

Abenojar et al. [6] investigated that the main problem in manufacturing of Al composite reinforced with B_4C using powder metallurgy processing is homogeneity. Compressibility was measured with the powder obtained by mechanical alloying to set up the optimal compaction pressure. The selected compaction pressure was 700MPa. Sinterability was assessed in $N_2/10H_2/0.1CH_4$ and argon climates during 30 min at distinctive temperatures. The best results were acquired at 635 ◦C and argon atmosphere as sintering conditions.

The mechanical and physical properties of Al/B_4C composites with 5 and 10 wt% reinforcements were discussed by Abdulla et al. [7]**.** Aluminium and B_4C powders were blended by ball milling, dried and sintered at 850°C for 2 hours. In this study, the parameters controlled were processing (milling) time of 8 and 16 hours. By using SEM morphology it is found that in the processing of 8 hours, aluminium particle size is larger than the processing of 16 hours. Hardness test was carried out to find out hardness of Al/B_4C composites with distinctive processing time. The Rockwell machine was utilized to determine the hardness each of specimens. The trial results demonstrated that the fine containing 5 and 10 wt% particles have the capacity to set up the feedstock with a decent flowability. The composites prepared by powder metallurgy have low densities and homogeneous microstructures.

Furthermore there is no interface reaction saw between the reinforcement and matrix by XRD examination. The hardness of Al/B_4C composites fabricated by powder metallurgy was high.

Preparation and description of Al–B_4C nanocomposites were researched by Sharifi et al. [8]. B_4C nanoparticles were blended with Al powder by ball processing to give Al–B_4C powder. Al–B_4C powders containing distinctive quantity (5, 10 and 15 wt%) of B_4C were hot pressed to make mass nanocomposite specimens. Merged specimens were described by hardness, compression and wear tests. Results demonstrated that the specimen with 15 wt% B_4C had the optimal properties. This specimen had an estimation of 164 HV that is fundamentally higher than 33 HV for pure Al. Also, the ultimate compressive strength of the specimen was calculated to be 485 MPa which is much higher than that for pure Al (130 MPa). The wear resistance of the nanocomposites improved significantly by increasing the B_4C content.

According to Mohanty et al. [9] it is essential to understand the manufacturing technique of Al-B_4Ccomposites because this kind of light weight materials have significant applications in industries. Therefore, the microstructure and physico-mechanical properties of Al-B_4C composites with 25 wt% boron carbide (B_4C) particulate reinforcement in aluminium 1100 matrix prepared at 873K were studied. The result reveals that with increase in wt% of B_4Cin composite there was a formation of boron rich Al–B from Al–B–C structure at grain boundaries. Due to this transition there is a decrease in interfacial strength. Thus with increase in B_4C reinforcement there was a decrement in strength of aluminium based boron carbide composite.

Viala et al. [10] examined the chemical reactivity of boron carbide (B_4C) with metallic aluminium (Al) at temperatures in-between 900 to 1273 K. Al-B_4C composite was analysed by X-ray diffraction (XRD), optical metallography (OM), scanning electron microscopy (SEM) and electron probe microanalysis (EPMA) after preparation by application of cold pressed heating on powder mixtures for 1-450 h under 10^5 Pa of purified argon atmosphere. It was observed that B_4C reacts with both solid and liquid form of Al in the given temperature range. When Al is in the solid state means temperature is lower than 933 K interaction takes place gradually, which results to the formation of ternary carbide (Al3BC) and to diboride (AlB2). When Al is in the liquid state means temperatures higher or equal to 933 K then reaction rate is very fast.

Preparation and Recycling features of composites reinforced with Boron Carbide were studied by Kommel et al. [11]. In this paper a study of composite based on multiphase lightweight boron carbide has been done via powder metallurgy technology. The composite is prepared by self-propagating high-temperature synthesis (SHS) method which is followed by a hot densification at liquid-state of aluminium binder phase. Heat treatment with vacuum was used at different conditions for optimization of composite properties. Also for spontaneous disintegration and recycling of the investigated material heat treatment in oxidizing environment was used.

2.3 Electro discharge machining

According to Saini et al. [3] Electric Discharge Machining (EDM) is a non-traditional machining process based on electro-thermal mechanism, where material removal mainly takes place due to thermal energy of the spark which is generated by electrical energy. High strength, temperature resistant alloys are mainly machined using EDM method means EDM is mainly used to machine difficult-to-machine materials. EDM can be use only with the materials which are electrically conductive.

Feasibility of applying EDM process on cast aluminium MMCs reinforced with SiCp was discussed by Hung et al. [13]. To analyse the effect of input parameters on MRR (metal removal rate), re-cast layer and surface finish, Statistical models of the process were developed. It was observed that due to SiC reinforcement MRR decrease because SiC reinforcement work as shield for aluminium and protect it from vaporization. When molten drop out it also take solid SiC particles with the matrix and due to dielectric effect some molten aluminium particles flushed away.

The effect of different input parameters on output parameters during the electric discharge machining of aluminium-silicon carbide was discussed by Karthikeyan et al. [14] by developing a mathematical model for above process. They discussed effect of different input parameters like SiC wt%, Ip (current) and Ton (pulse duration) on output parameters like MRR (material removal rate), TWR (tool wear rate) and SR (surface roughness) with the help of the mathematical models within the operating limits. The outcomes revealed that with increase in Ip, MRR increases but with increase in the wt% of SiC and Ton, MRR decrease. With increase in Ip and wt% of SiC, TWR increases but with increase in Ton, TWR decreases. With increase in the Ip, wt% of SiC and Ton, Surface roughness increases.

Effect of process parameters on performance parameters during electro discharge machining of Al composites reinforced with 15–35 vol% SiCp was discussed by Seo et al. [15]**.** They analysed that with increase in current (Ip) and pulse-on-time (Ton), MRR increase up to the optimal points and after that drop drastically. Tool wear and the average diameter error increase with increase in Ip and Ton.

The electro-erosion mechanism of during electro discharge machining (EDM) of Al/SiC composite was investigated by De Silva and Rankine [16]. They observed that due high temperature generation during EDM aluminium matrix melted and the SiC reinforcement which is surrounded by aluminium particles comes out and dielectric fluid flushed away these SiC particles.

Material removal rate (MRR) using single and continuous discharge in EDM of SiC/Al composite was studied by Hocheng et al. [17]. They found that in continuous discharge MRR increase with increase in Ip (current) and Ton (pulse on time) is much faster than single discharge in beginning but after some time it increase with slow rate. So, they recommended high Ip value and less Ton value for effective machining of Al/SiC composite.

Fatigue characteristics of machined surface of aluminium metal matrix composite reinforced with 15 vol% SiCp was investigated by Ramulu et al. [18]. They found that surface roughness is mainly caused due to surface micro-cracks, surface pitting and recast layer deposition. They also observed that with increase in MRR, the yield strength and ultimate strength of material were decrease.

The control (machining) parameters during rotary electro-discharge machining of Al/SiC (6025) composite using tube electrode was discussed by Mohan et al. [19]. The main objective of the research was to analyse the effects of Ip (current), Ton (pulse on time), wt% of SiCp, d (diameter of tube electrode), and electrode rotation speed on output parameters.

The optimal parameter setting for electro discharge machining of Al6063/SiCp MMC (metal matrix composite) were analysed by Dvivedi et al. [20]. There was a significant effect of density, porosity and electrical conductivity of composite on behaviour of material during EDM process. An optimal parameter setting was obtained for maximum metal removal rate, minimum tool wear and minimum surface roughness.

Hassan et al. [21], were investigated the effect of different machining parameters on performance parameters during electro discharge machining (EDM) of Tungsten Carbide. The main objective of this research was to analyse the effect of control parameters of EDM on performance characteristics like MRR (material removal rate), TWR (tool wear rate) and surface roughness.

2.4 Optimization

According to Prajapati [12] the necessary aspects which we should consider in different manufacturing industries is the proper selection of manufacturing conditions, mainly when manufacturing process is related to EDM (Electrical Discharge Machining). So optimization of different process and performance parameters is very important.

Optimization of different process parameters in the drilling operation of Al6061/Al_2O_3 composite using rotary electro discharge machine by using Taguchi method was performed by Wang and Yan [22]. The outcomes revels that for different control (machining) parameters tubular copper tool gives the optimal performance characteristics. Performance parameters like metal removal rate, tool wear rate and surface roughness confirm the results for optimal parameter settings.

Singh et al. [23] optimize the control parameters in EDM of Al composite reinforced with 10% SiCp using gray relational analysis. Taguchi method is employed for optimization but Taguchi method is single response optimization technique so it is used with gray relational methodology. Gray rational analysis convert the multi response into single response and this single response is then optimize using Taguchi method. The outcomes revels that there is significant improvement in the operation after applying optimal parameter setting.

The effect of various process parameters like Ip (current), Ton (pulse duration) and V (voltage) on performance parameters like metal removal rate, Tool wear rate and radial over cut during electro discharge machining of Al–4Cu–6Si alloy composite reinforced with 10 wt% SiCp using circular brass tool was discussed by Dhar et al. [24]. Full factorial plan was applied to analyze the results using three factors at three levels.

Ghoreishi et al. [25] were carried out research on Statistical modelling and optimal parameter setting in EDM of WC (tungsten carbide) composite reinforced with 6% Co (cobalt). They carried out EDM of WC/Co composite using circular copper tool to develop a mathematical model and find out the optimal parameter settings.

Yang et al. [26] studied the parameters in EDM using response surface analysis. In this paper a mathematical model is developed to show the relation between various process parameters and the accuracy of this model was tested by ANOVA. For achieving good machining and quality characteristics for EDM process, optimal parameter setting was obtained.

Rajesh et al. [27] optimize the process parameters of EDM using Genetic algorithm and Response Surface approach. Design of experiment is applied to develop a mathematical model for metal removal rate and surface roughness using Grey Relational approach. With the help of this developed model metal removal rate and surface roughness was optimized using Genetic Algorithm analysis.

Anand et al. [28] were carried out research on optimization of process parameters in EDM of AISI 202 stainless steel using grey relation approach. This paper describe the selection of machining parameter Ip (Discharge current), Ton (Pulse duration), Toff (Pulse off time) in electro discharge machining of AISI 202 Stainless steel material to optimize the performance parameters like material removal rate and surface roughness using grey relational approach. The experimental work in this research is carried out to know effect of process parameters on the metal removal rate and surface roughness. Grey Relational grade is used to find the optimal parameter.

Chapter 3: Experimentation

This chapter describes the details of experimental work done in present study. The details of each step for fabrication of Al, B_4C MMC with specific composition of the given raw material are also described. Then machining is performed on the prepared MMC for further analysis. Scanning Electron Microscopy of prepared MMC is done for micro structural analysis. The images for each step are provided for the sake of clarity and visual basics.

3.1 Raw Materials

Al alloy powders (A2265) and B_4C powder were purchased from RFCL Limited, New Delhi, India. The composition and specification are described below:

- Al Powder - The Al alloy powder contains 99.7% Al, 0.1% Cu and 0.1% Fe. The atomic weight of Al powder is 26.88 and particle size is 110 meshes.
- B_4C Powder – B_4C powder is purchased from open market (Loba Chemie-Pvt. Ltd.) with 98% metal. The particle size is of 140 meshes.

3.2 Powder metallurgy Processing

The Al, SiCp MMCs are fabricated using powder metallurgy processing which consists of three steps Mixing of Powders using ball mills (Blending), cold uniaxial pressing (Compacting) and sintering. The steps used are described below [6-7]:

- **Mixing of powders -** In the first stage, we need to take Al and B_4C powders in different proportion and after checking the strength of these samples we found an optimum proportion value which is 20% boron carbide by weight. Now According to our sample size which is of 5 gm we need to add 1 gm boron carbide with 4 gm aluminium by means of a planetary ball mill (Model-PULVERISETTE-5, Make-FRITSCH, Germany) which is shown in Fig. 3.1. The mixing is done for 200000 revolutions and after that the sample is taken out.

Fig. 3.1: Ball planetary mill machine

- **Compaction of the mixed powder -** In the second stage, Al + 20% B_4C powder (5gm sample) was uniaxially compacted, using a Cold Uniaxial Pressing Machine (Make- SOILLAB, Maximum load: 20 tonnes, Type-Hydraulic)which is shown in Fig. 3.2. The diameter of dye used for compaction was 25mm and the pressure applied was 1018 bar. So we got a green compacted sample in second stage which is shown in Fig. 3.3.

Fig. 3.2: Cold Uniaxial Pressing Machine

Fig. 3.3: Compacted sample

- **Sintering of Compact Samples -** Sintering is third and final stage of powder metallurgy process which is carried out in horizontal tubular furnace (Make-Naskar and Co., Type-Vacuum and control atmosphere, Maximum temperature-1600^{o}C) with argon atmosphere at a pressure of 1 bar as shown in Fig. 3.4. A batch of 12 green samples was sintered at the temperature of 640 degree Celsius just below the melting point of aluminium for holding time of 1 hour. Then furnace is left to cool to room temperature (cooling rate-5^{o}C/min) for a time span of 24 hours. At the end of the third stage we got the sintered sample which is shown in Fig. 3.5.

Fig. 3.4: Tubular furnace Fig. 3.5: Sintered sample

3.3 Density Calculation

The actual densities of the samples can be calculated by calculating the ratio of average mass of the samples to average volume of the samples which comes out 2.037x10^{-3} gm/ mm^{3}. Theoretically, the densities of the composites are measured by using the formula given below:

$$\rho_C = \frac{1}{\left\{\left(\frac{X_{Al}}{\rho_{Al}}\right) + \left(\frac{X_{B_4C}}{\rho_{B_4C}}\right)\right\}}$$

Where, ρ_C = Composite density (gm/mm^3)

X_{Al} = Weight fraction of aluminium (0.8)

ρ_{Al} = Density of aluminium (2.70x10^{-3} gm/ mm^3)

X_{B_4C} = Weight fraction of boron carbide (0.2)

ρ_{B_4C} = Density of boron carbide (2.52x10^{-3} gm/ mm^3)

After calculation we got $\rho_C = 2.661\text{x}10^{-3}$ gm/ mm^3

Density of the copper tool is (ρ_T) $8.96\text{x}10^{-3}$ gm/ mm^3

3.4 Electro Discharge Machining

After preparation of specimen through powder metallurgy processing we will go for electro discharge machining (EDM) of prepared specimens. EDM set up consists of a machine tool PS 50ZNC (Pulse generator type-MOSFET, Connected load-6 KVA, Work table dimension-550X350mm, Max. Job hight-250mm) which is a die sinking machine as shown in Fig. 3.6. EDM is an electro thermal process which requires a dielectric medium, so the work piece (MMC) and tool should be electrically conductive. Copper tool is used as cathode (Negative electrode) and the work piece used as anode (Positive electrode). The mechanism of EDM is melting and vaporization so the material removal takes place due to high temperature (10000-12000°C)generation on electrodes (work piece and tool)caused by ionization (spark generation) in between electrode gap [30-31]. Material removes in the form of debris from tool and work piece and we get the negative imprint of tool on the work piece as shown in Fig. 3.7. The dielectric fluid used is transformer oil. The copper tool used is shown in the Fig. 3.8.

Fig. 3.6: Electro discharge machine

Fig. 3.7: Machined samples

Fig. 3.8: Copper Tool

3.4.1 Important parameters EDM

In EDM process there are some input parameters which control the machining conditions known as process parameters and some out parameters which shows the product quality known as performance parameters. All these input and output parameters are very important for getting a better machining condition and product quality [12].

3.4.1.1 Process (input) parameters

Some of important process parameters are described below:

- **Discharge current (Ip) -** Discharge current is average current measured by ammeter over a complete cycle. Theoretically average current is product of duty cycle and peak (maximum) current. Discharge current is very important parameter because it is directly proportional to MRR.
- **Voltage (V) –** Voltage is the potential difference between the electrodes. Voltage is supplied using a DC power source. Voltage is set according to spark gap, as spark gap increase the supply voltage is also increase.
- **Pulse on time (Ton) –** This is the time for which spark generation and hence material removal takes place. So Ton should be high to increase the MRR.

- **Pulse off time (Toff) –** This is the time for which spark is off means no material removal takes place. This time allows the removed material (debris) to wash out from spark gap.
- **Spark gap –** It is the gap between two electrodes (tool and work piece) where spark generation takes place. For a constant voltage supply the spark gap should be constant. As material removal takes place spark gap increased. So a servo control mechanism is used to maintain spark gap constant.
- **Duty cycle (τ) –** Duty cycle is the ratio of pulse on time to total cycle time. It shows the fraction of on time relative to total cycle time.

$$\tau = \frac{Ton}{Ton + Toff}$$

Where, τ = Duty cycle

Ton = Pulse on time

$Toff$ = Pulse off time

3.4.1.2 Performance parameters (Output)

Some of important performance parameters are described below:

- **Material Removal Rate (MRR)** - MRR is defined as volume of material removed per unit time. MRR is expressed by the formula given below:

$$MRR = \frac{(W_i - W_f)}{(\rho_C \times T)}$$

Where, W_i = Initial weight of work piece (gm)

Wf = Final weight of work piece (gm)

ρ_C = Density of composite (gm/mm^3)

T = Time of machining (min)

- **Tool Wear Rate (TWR) -** TWR is defined as volume of material removed from tool per unit of time. The formula for TWR is given below:

$$TWR = \frac{(T_i - T_f)}{(\rho_T \times T)}$$

Where, T_i = Initial weight of tool (gm)

T_f = Final weight of tool (gm)

ρ_T = Density of tool (gm/mm^3)

T = Time of machining (min)

For calculation of MRR and TWR we need to measure the initial weight and final weight of tool and work piece which is measured by electronic weight measuring machine (Model-Sansui vibra, Shinko Denshi co. Ltd., Japan) as shown in Fig. 3.9.

Fig. 3.9: Weight Measuring Machine

- **Surface Roughness (Ra) -**The surface profiles of the EDM specimens are measured by utilizing a portable stylus type profilometre like Talysurf (Taylor Hobson) shown in Fig. 3.10. It has a stylus which skids over the surface to measure the roughness.

Fig. 3.10: Stylus Type Profilometre

3.5 Design of Experiment

Design of experiment (DOE) is a scientific approach to study the effect of multiple variables simultaneously. DOE has advantages of less number of experiments required for preciseness in effect estimation, improvement quality of a product or process [24]. EDM is such a process in which a number of control factors collectively determine the output responses. Hence, in the present work one statistical technique called Taguchi method is used to optimize the process parameters leading to the improvement in quality characteristics of the part under study. The most important step in the DOE lies in the selection of the control factors and their levels. EDM process has large number of process parameters but based on different literature review three machining parameters namely, discharge current (Ip), voltage (V) and pulse-on-time (Ton) are identified and set at three levels which is shown below in Table 3.1.

Table 3.1: Domain of experiment

Factors	Units	Level 1	Level 2	Level 3
Current (Ip)	[A]	7	8	9
Voltage (V)	[V]	60	70	80
Pulse on Time (Ton)	[μs]	75	100	150

For further experimentation L9 orthogonal array has been selected which is shown it Table 3.2. Considering all three control parameters at different levels total 9 experiments have been performed [32].

Table 3.2: Taguchi L_9 orthogonal array

Run No.	Ip	V	Ton
1	1	1	1
2	1	2	2

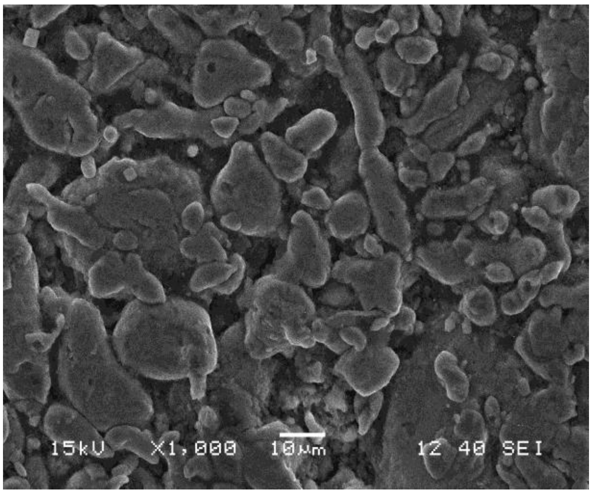
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

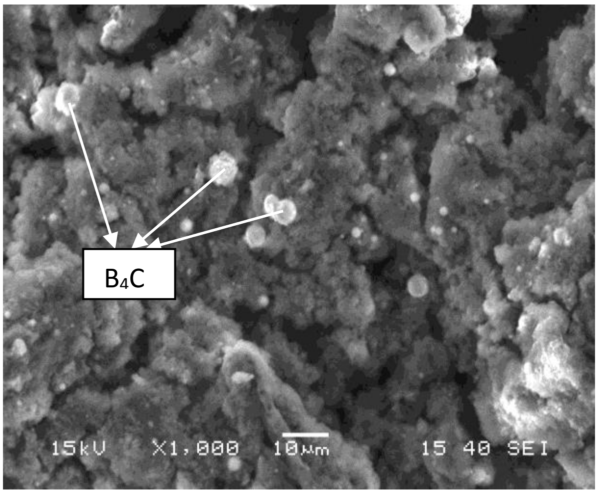
3.6 Microstructure analysis

Micro structural test was performed to find out the distribution of Al (aluminium) and B_4C (boron carbide) particles in the composite. The micro structural analysis of samples has been done using Scanning Electron Microscope (SEM) (JEOL JSM 6480 LV) as shown in Fig. 3.11.

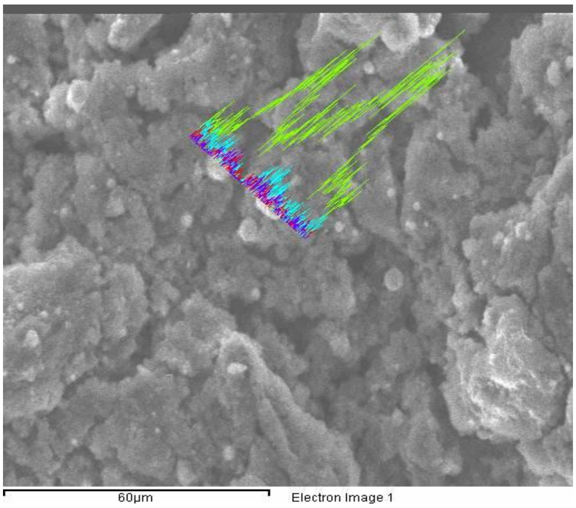
Fig. 3.11: Scanning Electron Microscope

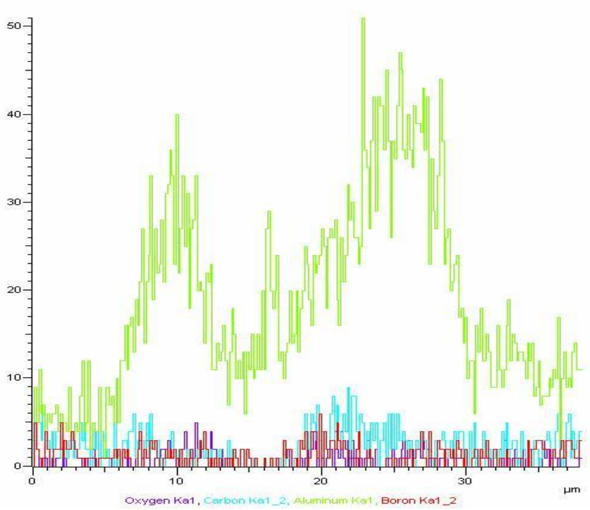
Micrographs of samples taken before and after the electro discharge machining are shown below in the Fig. 3.12.





(a) (b)





(c) (d)

Fig. 3.12: Micrographs showing the distribution of the reinforcement (20% B_4C) in the composite (a) Unmachined surface (b) Machined surface (c) Graphical representation in machined surface (d) Graphical representation of different materials in composite

In SEM we get the images when electron beam pass through the object. But electron beam can pass through the object which is electrically conductive. In our sample which is placed in SEM B_4C is also present which is a ceramic material and ceramics are electrically nonconductive so electron beam cannot pass through it. The electrons which do not pass through B_4C surrounded it from all direction this is known as charging of B_4C and we get a white distorted image (Image b) of B_4C in microstructure. On the other hand Al is a very good conductor of electricity so electron beam pass through it and we get a clear black image of Al in microstructure.

In graphical representation (Image c and d) there is no carbon in between boron particles but carbon is with boron particles so white image represent boron carbide in microstructure. During machining Al gets oxidise so oxygen is also present in the sample which can be seen on microstructure.

Chapter 4: Methodology and data analysis

Correct selection of manufacturing conditions is one of the most important aspects in any manufacturing processes and, particularly, in processes related to Electrical Discharge Machining (EDM) [12]. So optimization of different process and performance parameters is very important. Optimization term is opted from a Latin word "optime", which means the best. Optimization consists of finding the best result which may be maximum or minimum depending upon the manufacturing situations. In machining of Al/ B_4C composite by EDM the prime objective is to optimize the performance parameters (MRR, TWR and Ra) while maintaining the process parameters (V, Ip and Ton). Taguchi is a single response optimization technique means this method optimize one parameter at a time so this method cannot be applicable under the given circumstances. In order to optimize the multi responses, the process has been first modelled by means of TOPSIS then we will go for Taguchi optimization technique.

4.1 TOPSIS

TOPSIS stands for "Technique for order preference by similarity to ideal solution". This method was first discovered by Hwang and Yoon in 1981. The basic concept of this method is that the selected alternative must be at the minimum distance from the positive ideal solution and at the maximum distance from negative ideal solution. Positive ideal solution is related with the maximization the profit criteria and minimization of loss criteria, on the other hand the negative ideal solution related with minimization of the profit criteria and maximization the loss criteria [33-34]. TOPSIS method consists of following steps:

Step 1: In this method we develop decision matrix. This method consists of alternatives in the row and attributes in the columns. The matrix format can be expressed as:

$$D = \begin{array}{c} a_1 \\ a_2 \\ . \\ a_i \\ . \\ a_m \end{array} \begin{bmatrix} x_{11} & x_{12} & x_{13} & . & x_{1n} \\ x_{21} & x_{22} & x_{23} & . & x_{2n} \\ . & . & . & . & . \\ x_{i1} & x_{i2} & x_{i3} & . & x_{in} \\ . & . & . & . & . \\ x_{m1} & x_{m2} & x_{m3} & . & x_{mn} \end{bmatrix} \tag{4.1}$$

Here, $a_i (i = 1,2,3,.....m)$ represents all possible alternatives, $x_j (j = 1,2,3,....n)$ represents the attributes related to performance of alternatives, $j = 1,2,3,....n$ and x_{ij} represents the performance of a_i with respect to attribute j.

Step 2: In this step the above decision matrix is normalize and we get normalized decision matrix r_{ij}. The formula for r_{ij} is given below:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4.2}$$

Here, r_{ij} represents the normalized performance of a_i with respect to attribute x_j.

Step 3: Now weighted normalized decision matrix can be calculated by using the formula $V = w_j r_{ij}$ and we get weighted normalized decision matrix $V = \lfloor v_{ij} \rfloor$. (4.3)

Here, $$\sum_{j=1}^{n} w_j = 1 \tag{4.4}$$

Step 4: Now positive ideal solutions (best) and negative ideal solutions (worst) are need to be calculated in this step. The solutions can be represented as:

- Positive ideal (best) solution:

$$\begin{aligned} a^+ &= \{(\max v_{ij}, j \in J), (\min v_{ij}, j \in J')\} \\ &= \{v_1^+, v_2^+, v_3^+, ...v_j^+, ...v_n^+\} \end{aligned} \tag{4.5}$$

- Negative ideal (worst) solution:

$$a^{-} = \{(\min v_{ij}, j \in J), (\max v_{ij}, j \in J^{'})\}$$
$$= \{v_1^-, v_2^-, v_3^-, ...v_j^-, ...v_n^-\} \qquad (4.6)$$

Here,

$J = \{j = 1,2,3,.....n\}, J^{'} = \{j = 1,2,3,......n\}$

J and $J^{'}$ associated with the beneficial and non-beneficial attributes.

Step 5: Now we need to calculate Euclidean distance of each alternative from positive ideal and negative ideal solution by using the following equations:

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2}, i = 1,2,3,......m \qquad (4.7)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2}, i = 1,2,3,.......m \qquad (4.8)$$

Step 6: Now Calculation the relative closeness to the ideal solution for each alternative by using the equation given below:

$$C_i^+ = \frac{D_i^-}{D_i^+ + D_i^-}, i = 1,2,3,......m; 0 \le C_i^+ \le 1 \qquad (4.9)$$

Step 7: Now rank according the preference order. The alternative with maximum relative closeness should be the best choice.

In present work C_i^+ has been termed as MPCI (Multi-Performance Characteristic Index) which is optimized by Taguchi method.

4.2 Taguchi method

Taguchi method is an efficient tool for determining the effectiveness of a design by measuring the effect of input design parameters on output performance characteristics. This method is developed by Dr. Genichi Taguchi in the year 1940 also known as "*Taguchi's* *philosophy*". The main objective of this method is to enhance the fundamental actions of any product or process and thus resulting a flexible or adaptable design. Hence the Taguchi method is the most powerful and dynamic tool in the design of experiment methods [35].

Taguchi method is a three-step design process which is system design, parameter design and tolerance design. In this present work parameter design is used to find out the nominal values for relevant process parameters. Parameter design is a systematic approach to find out the optimum settings for the design parameters in order to minimize performance variability. Taguchi method uses a statistical tool to measure performance characteristics known as signal-to-noise (S/N) ratio and tries to select the design parameter in order to maximize the S/N ratio. The term signal stands for mean value of the performance characteristic and noise stands for the variability of the performance characteristic. Hence S/N ratio consists of both mean and variability of performance characteristics [36].

4.2.1 Performance evaluation using Taguchi's S/N ratio

Taguchi method uses a statistical tool to measure performance characteristics known as signal-to-noise (S/N) ratio to find out the optimum settings for the design parameters and it (S/N ratio) consists of both the mean and the variability of performance characteristics [36-37]. This method tries to select the design parameter in order to maximize the S/N ratio because higher the S/N ratio the more balanced the adoptable is the performance quality. There are three criterions of signal-to-noise ratios which are lower-the-better (LTB), the higher-the-better (HTB), and nominal-the-best (NTB). In present work three responses are considered material removal rate (MRR), tool wear rate (TWR) and surface roughness (Ra). Tool wear rate and surface roughness are need to be minimize whereas material removal rate is need to be maximize. So, for calculating S/N ratio of Tool wear rate and surface roughness LTB criterion and for calculating S/N ratio of material removal rate HTB criterion should be selected. The equation for aforesaid three criterions is given below:

- **Lower-is-Better (LTB) criterion:**

$$S/N\ ratio = -10\log\left(\frac{1}{n}\sum y^2\right) \tag{4.10}$$

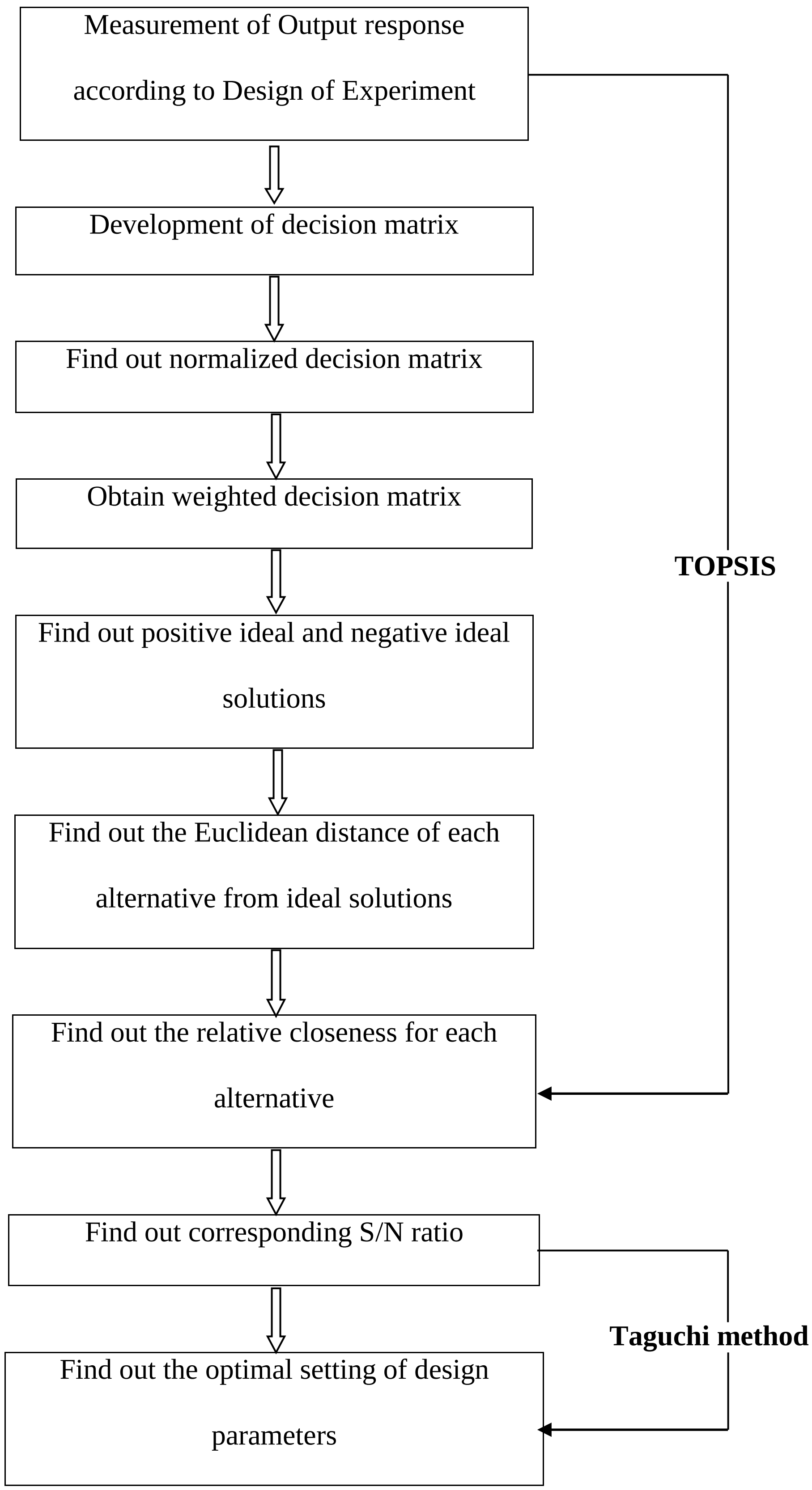
- **Higher-is-Better (HTB) criterion:**

$$S/N\ ratio = -10\log\left(\frac{1}{n}\sum \frac{1}{y^2}\right) \tag{4.11}$$

Here, y is average of all observed value and n is number of observations.

We cannot use Taguchi method for getting a single optimal setting of design parameters considering more than one performance characteristics. So this method is useful only for optimization of a single performance characteristic. Optimization of design parameters with more than one performance characteristics are still an area of research.

4.2.2 Steps involved in the proposed methodology (TOPSIS combined with Taguchi method)



4.3 Electro discharge machining data analysis

Now we need to analyse the experimental data by the optimization technique discussed above and obtain the optimal parameter setting. By using TOPSIS integrated Taguchi method the optimal parameter setting for electro discharge machining is obtained. The three control parameters of electro discharge machining current (Ip), voltage (V) and pulse on time (Ton) are varied at three different levels. Hence, Taguchi l_9 orthogonal array has been selected for further experimentation which is shown in the Table 4.1.

Table 4.1: Taguchi L_9 orthogonal array for EDM process parameters

Run No.	Ip	V	Ton	Ip (amp)	V (volt)	Ton (µs)
1	1	1	1	7	60	75
2	1	2	2	7	70	100
3	1	3	3	7	80	150
4	2	1	2	8	60	100
5	2	2	3	8	70	150
6	2	3	1	8	80	75
7	3	1	3	9	60	150
8	3	2	1	9	70	75
9	3	3	2	9	80	100

The experimental data table is shown below in the Table 4.2 in which the different values of performance parameters are evaluated according to each run of process parameters.

Table 4.2: Experimental data of EDM

Run No.	Ip (amp)	V (volt)	Ton(µs)	MRR(mm^3/min)	TWR(mm^3/min)	Ra(µm)
1	7	60	75	2.787	0.074	5.667

2	7	70	100	7.779	0.011	7.346
3	7	80	150	6.163	0.022	6.761
4	8	60	100	5.496	0.041	9.864
5	8	70	150	2.954	0.007	6.583
6	8	80	75	5.449	0.083	7.973
7	9	60	150	11.354	0.055	5.921
8	9	70	75	12.100	0.111	8.324
9	9	80	100	16.986	0.178	7.635

4.3.1 Data analysis: Application of TOPSIS integrated with Taguchi method

First apply TOPSIS method according to the steps which are discussed before than apply Taguchi approach to find out the optimal setting. So first of all decision matrix has been obtained using Eq. 4.1 and shown in Table 4.3. Normalisation of decision matrix has been done according to Eq. 4.2 and we obtain the normalised decision matrix which is shown in Table 4.4. After this weighted normalized decision matrix has been developed using Eqs. 4.3-4.4 and shown in the Table 4.5. For calculation of weighted normalized decision matrix we need to give equal weights to all the parameters and as there are three performance parameters so weight given to each parameter is equal to 0.3. Positive ideal and negative ideal solutions have been calculated using Eqs. 4.5-4.6 and shown in the Table 4.6. Now distance of each alternative from ideal solution has been evaluated using Eqs. 4.7-4.8 and shown in Table 4.7. Finally relative closeness has been calculated using Eq. 4.9 and shown in Table 4.8. Now relative closeness has been optimized (maximized) using Taguchi method. S/N ratio has been calculated considering Higher-is-Better (HTB) criteria because if relative closeness values are high results are more close to ideal solution. The value of S/N ratio against each run of relative closeness has been shown in Table 4.8. The optimal combination of parameters is obtained from S/N ratio plot (mean effect plot) using MINITAB-16 software which has been verified by confirmatory test. The S/N ratio plot has been shown in Fig. 4.1.

Table 4.3: Decision matrix

Run No.	MRR (mm^3/min)	TWR (mm^3/min)	Ra (µm)
1	2.787	0.074	5.667
2	7.779	0.011	7.346
3	6.163	0.022	6.761
4	5.496	0.041	9.864
5	2.954	0.007	6.583
6	5.449	0.083	7.973
7	11.354	0.055	5.921
8	12.100	0.111	8.324
9	16.986	0.178	7.635

Table 4.4: Normalised decision matrix

Run No.	N-MRR	N-TWR	N-Ra
1	0.099139	0.297841	0.253716
2	0.276713	0.044274	0.329692
3	0.219229	0.088547	0.302695
4	0.195503	0.16502	0.441618
5	0.105079	0.028174	0.294726
6	0.193831	0.334065	0.356957
7	0.403562	0.221368	0.265087
8	0.430419	0.446761	0.372671

9	0.604223	0.716428	0.341824

Table 4.5: Weighted normalised decision matrix

Run No.	W-MRR	W-TWR	W-Ra
1	0.032716	0.098287	0.083726
2	0.091315	0.01461	0.108798
3	0.072346	0.029221	0.099889
4	0.064516	0.054457	0.145734
5	0.034676	0.009297	0.097259
6	0.063964	0.110241	0.117796
7	0.133176	0.073051	0.087479
8	0.142038	0.147431	0.122982
9	0.199394	0.236421	0.112802

Table 4.6: Positive and Negative ideal solutions

	MRR	TWR	Ra
Positive ideal solution	0.199394	0.009297	0.083726
Negative ideal solution	0.032716	0.236421	0.145734

Table 4.7: Distance measures of alternatives from ideal solutions

Run No.	D^+	D^-
1	0.188947	0.151413
2	0.111076	0.232375
3	0.129613	0.21588

4	0.155166	0.184722
5	0.165273	0.232247
6	0.172313	0.13296
7	0.091998	0.200438
8	0.154634	0.142787
9	0.228978	0.1699

Table 4.8: Relative closeness and S/N ratio

Run No.	C^+	S/N ratio	Predicted S/N ratio
1	0.444861	-7.03551	-2.82419
2	0.676589	-3.3935	
3	0.624847	-4.08453	
4	0.543479	-5.29634	
5	0.58424	-4.66817	
6	0.435544	-7.21935	
7	0.685408	-3.28101	
8	0.480084	-6.37365	
9	0.425945	-7.41294	

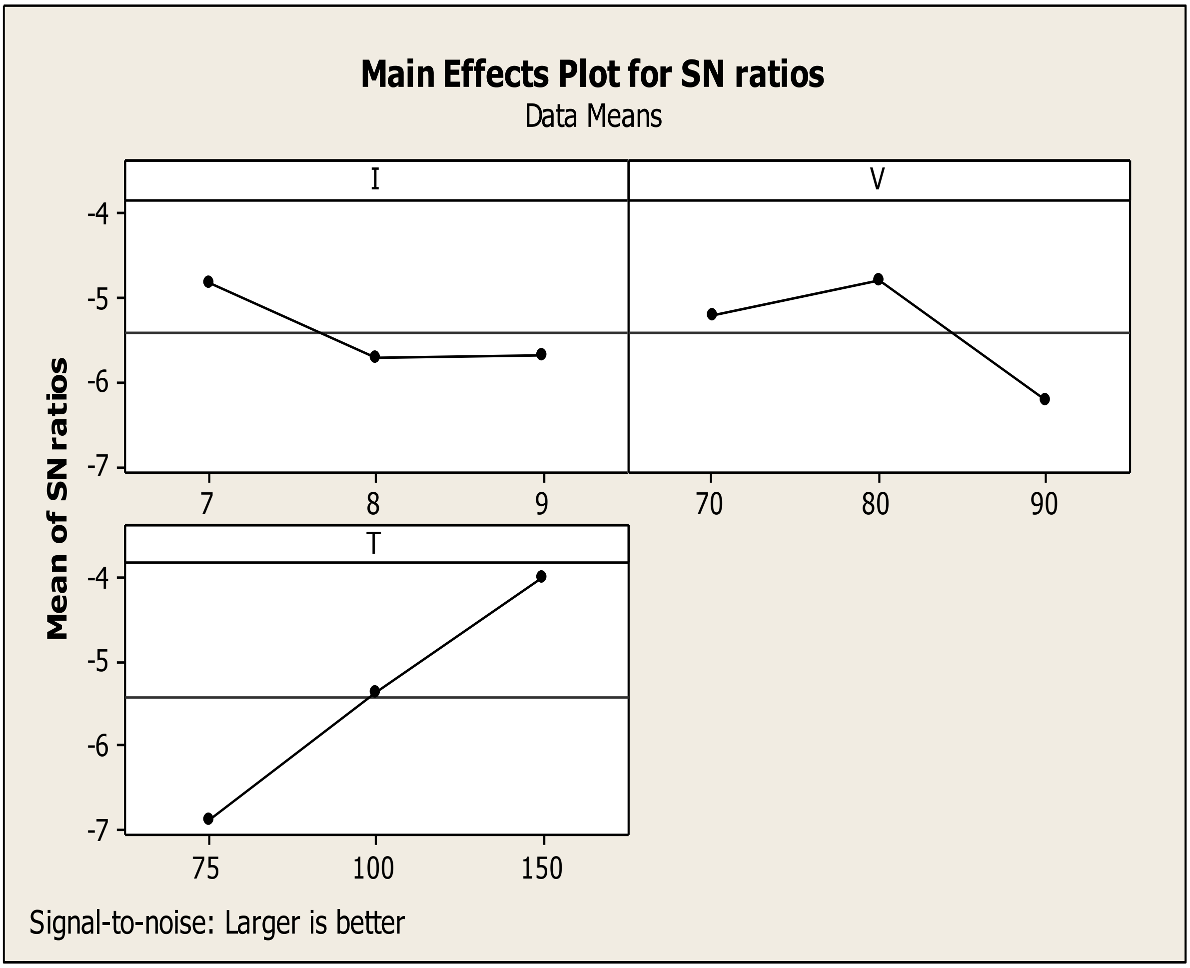


Fig. 4.1: S/N ratio plot

The optimal combination obtained from the S/N ratio plot (Fig. 4.1) is shown below in Table 4.9.

Table 4.9: Optimal combinations of process parameters

Factor	Ip	V	Ton
Level	7 amp	80 volts	150 µs

Chapter 5: Conclusions and Future scope

5.1 Conclusions

In this project work Al/B_4C metal matrix composite (MMC) has been prepared through powder metallurgy process and the effect of three process parameters (MRR, TWR and SR) of EDM on Al/B_4C MMC has been discussed. Taguchi method refers to optimize a single-response problem, so a hybrid optimization technique (TOPSIS combined with Taguchi method) is used to optimize control parameters. In the present study based on the data analysis and experimental results the following conclusions can be drawn.

MPCI (multi performance characteristic index) is equivalent to single response and control parameters (Ip, V and Ton) have significant effect on it. So the MPCI value is analyzed by Taguchi's method and we get S/N ratio plot. Now the optimal combinations of process parameters obtained from S/N ratio plot are discharge current 7 amp, voltage 80 volts, pulse on time 150 µs and corresponding performance parameters are MRR 6.163 mm^3/min, TWR 0.022 mm^3/min, Surface roughness 6.176 µm. So from this study it can be concluded that difficult-to-cut materials like Al/B_4C can be machined easily by the non-conventional machining process like EDM with better machining and quality characteristics.

5.2 Future Scope

The present work can be extended for further quality improvement like other machining parameters and material parameters can also be taken into account for experimental analysis. Other machining parameters like flushing pressure, duty factor, dielectric fluid etc. can also be considered for analysis. Different material parameters like % of Al and B_4C, mesh size Al and B_4C powders, sintering temperature etc. can also be adopted for analysis. Other mathematical models can also be used to optimize the control parameters of EDM on MMCs and hence to improve machining and quality characteristics.

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